Cold Nuclear Matter effects on Quarkonia production from PHENIX

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(for the PHENIX Collaboration)

University of Tennessee

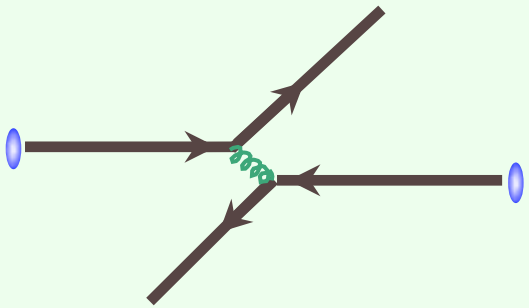
2014 RHIC & AGS Annual Users' Meeting

PHENIX

Why p(d)+A collisions?

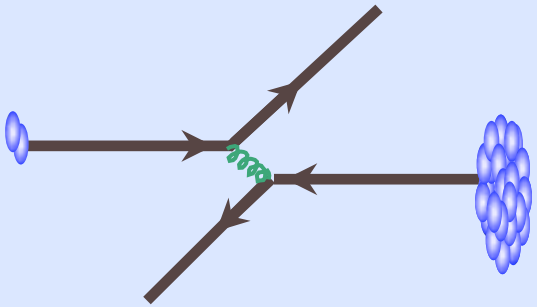
A very exciting time to talk about p(d)+A collisions

p+p measurements



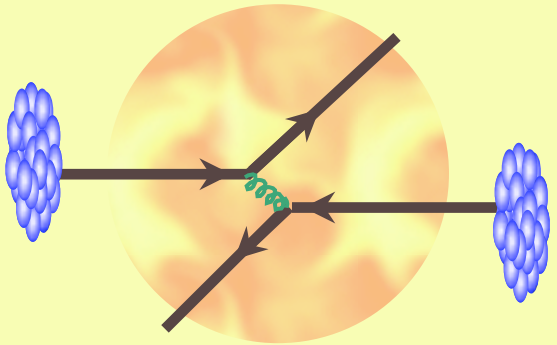
Baseline

d+A measurements



probe CNM effects

A+A measurements



probe HNM+CNM effects

QM 2012
Not enough particles to have collective behavior, control experiment

QM 2014
Are we sure?

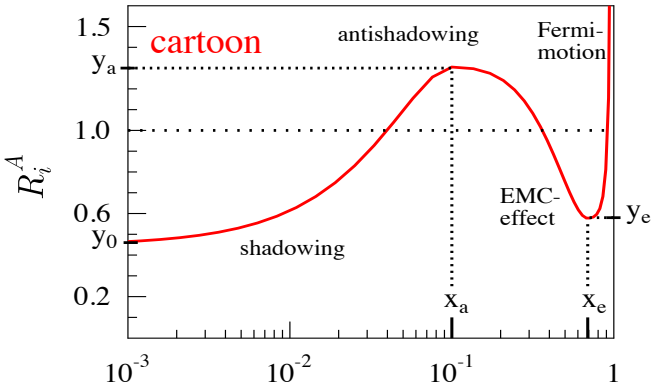
Motivation

Understand cold nuclear matter effects in order to disentangle hot nuclear (QGP related) effects in A+A collisions.

Cold nuclear matter effects:

- Nuclear PDF: Gluon PDF in nucleus ≠ nucleon PDF
  - Varies with x,Q^2.
  - Nuclear PDFs available: EPS09, EPS09s, EKS98, nDSg and others.

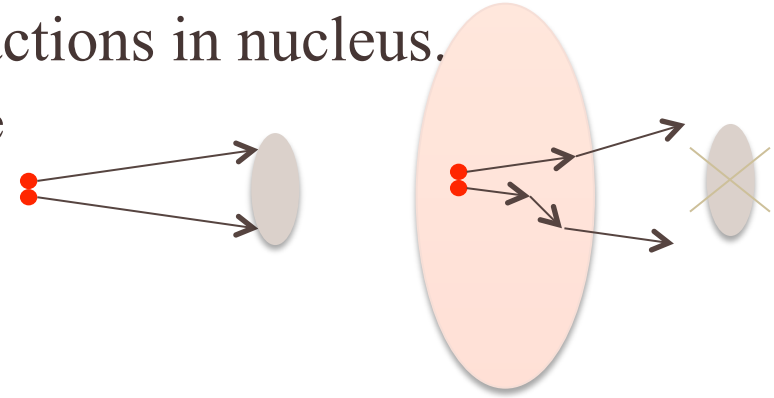
$$R_i^A(x,Q^2) = \frac{f_i^A(x,Q^2)}{A\, f_i^{\text{nucleon}}(x,Q^2)}, \quad f_i = q, \bar{q}, g,$$



- Cronin: Multiple scattering of the incoming parton on the nucleus.
- Energy loss: Medium induced gluon radiation modifies the initial state gluon kinematics.

Motivation (contd..)

- Nuclear absorption (Quarkonia specific): Due to size of q-$q$bar bound state, break up due to interactions in nucleus.
  - Depends on the nuclear crossing time at the kinematic domain.



- Possibly more..

Note:

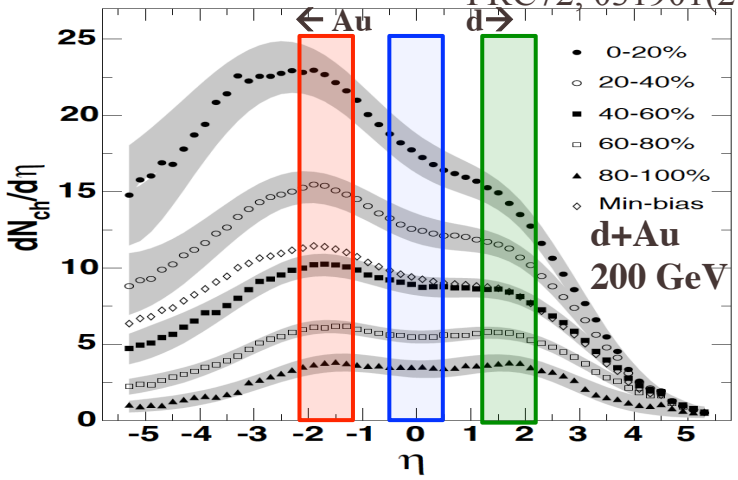
- Gluon shadowing affects the underlying heavy flavor yield.
- Absorption reduces the fraction of heavy quarks forming bound quarkonium.

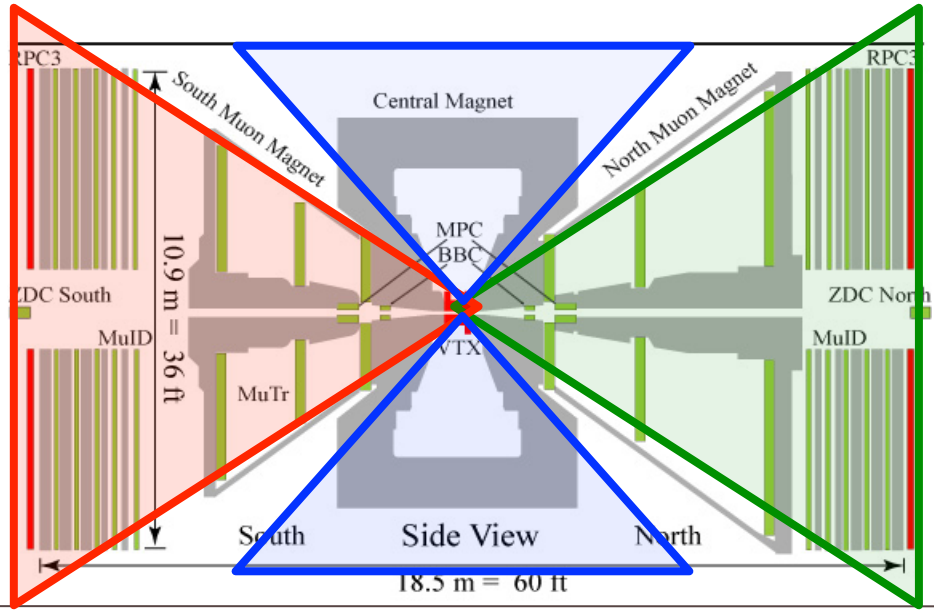
What can we do in PHENIX?

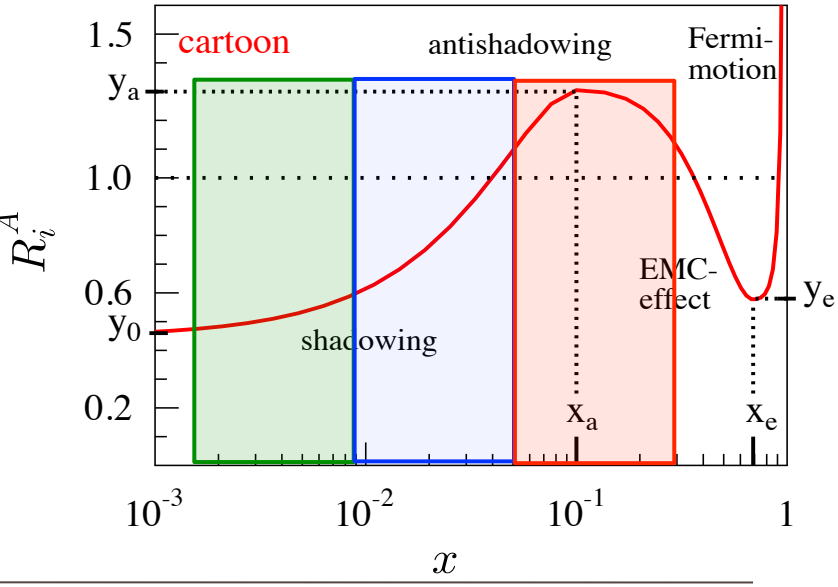
PHENIX

- PHENIX recorded *d*+Au collisions in 2003 and higher statistics in 2008.
- Quarkonia measured:
  - Central Arms: J/ψ, ψ', Υ, χ_c
  - Muon Arms: J/ψ, ψ', Υ
- Wide x coverage:

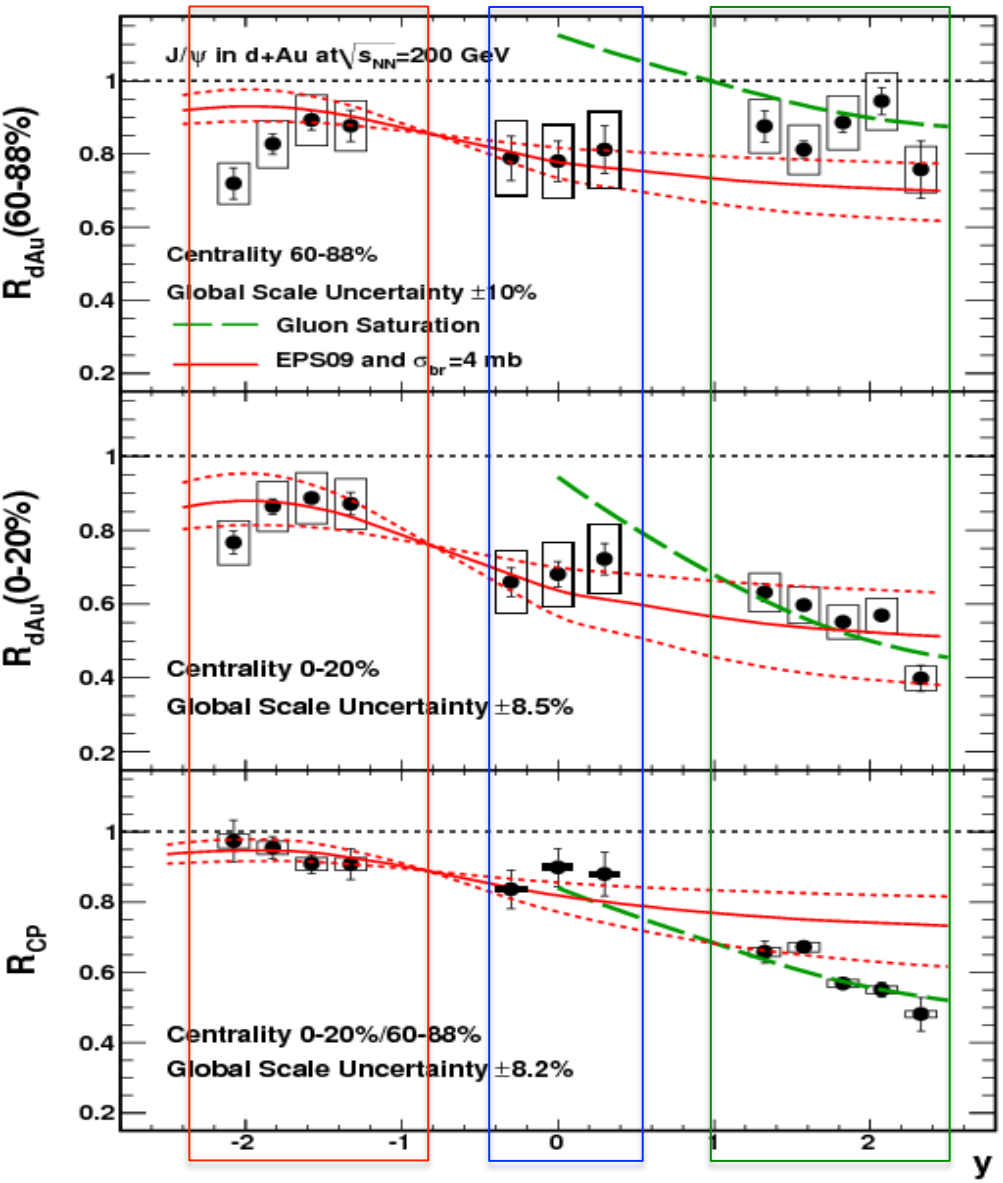
PRC72, 031901(2005)

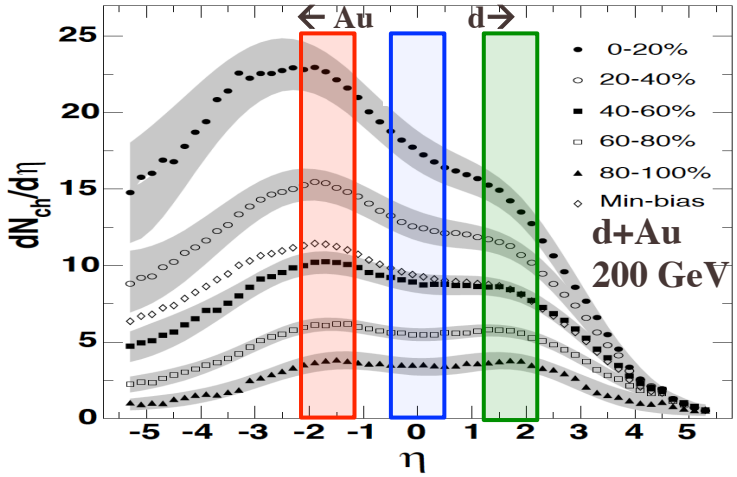






J/ψ suppression in d+Au



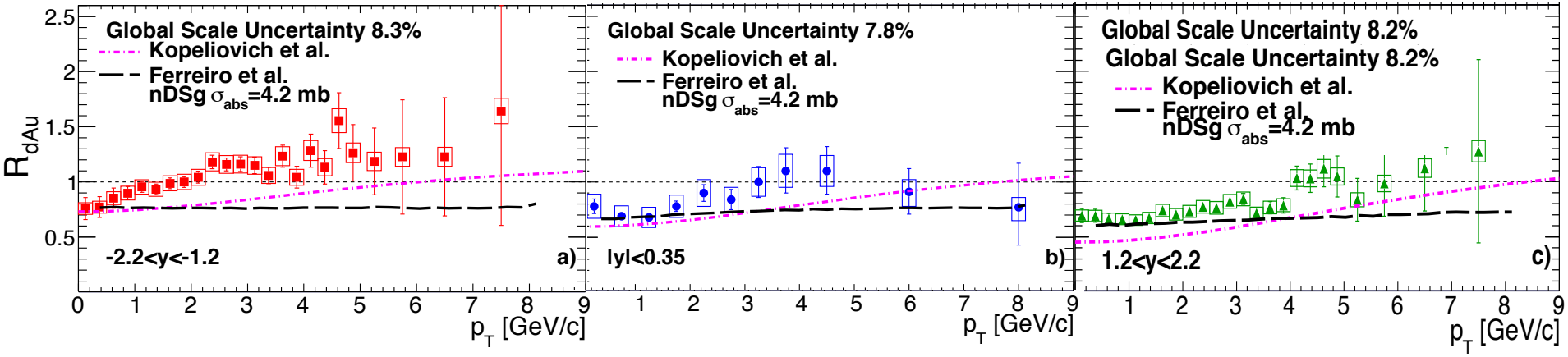


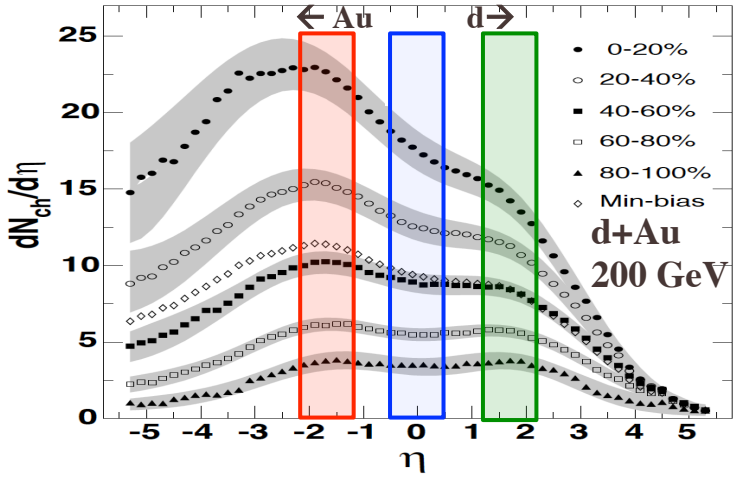
- (Solid Red curves) A reasonable aggreement with EPS09 nPDF + σ_{br} = 4 mb for central collisions but not peripheral.
- (Dashed green line) CGC calculations. (Nucl. Phys. A 770(2006) 40)

Nuclear PDF is nuclear thickness dependent.

PRL 107, 142301 (2011)

J/ψ R_{dAu} vs. p_T (all centrality)





R_{dAu} rises out to p_T~5 GeV/c at all rapidities.

R_{dAu} trend is different at backward rapidity.

Calculations from Ferrerio et al. : Shadowing + σ_{br} model (no Cronin) does not match the qualitative trend. (arXiv1201.5574)

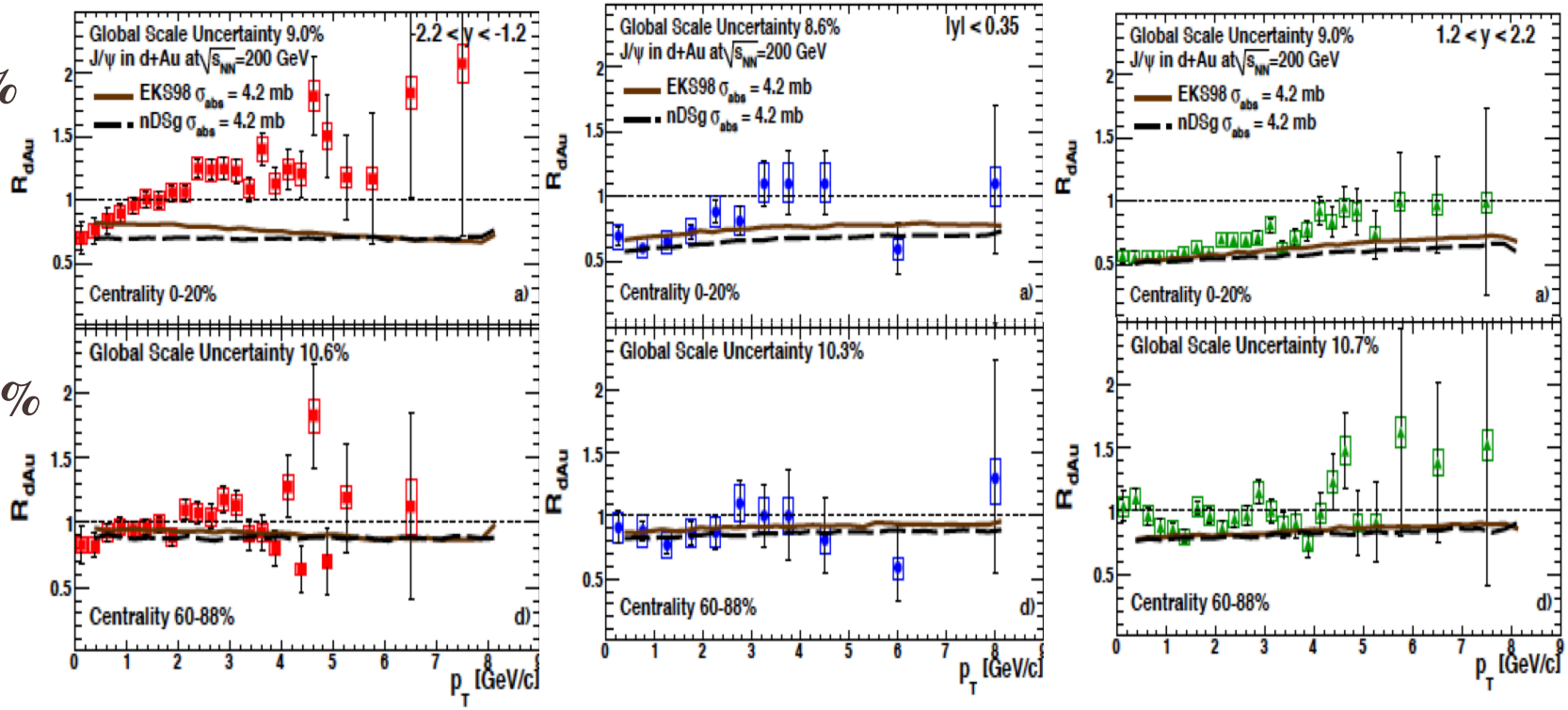
Model by Kopeliovich et al. includes Cronin and σ_{br} prediction, qualitatively matches the p_T shape. (Nucl. Phys. A 864, 203 (2011))

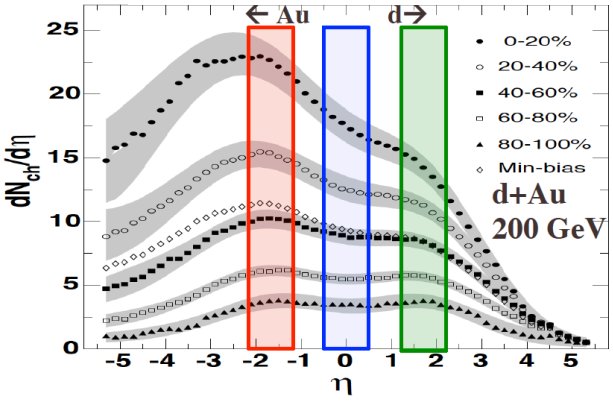
PRC 87, 034904 (2013)

J/ψ R_{dAu} vs p_T (centrality bins)

0-20%

60-88%





Stronger modification in central. R_{dAu} ~1 for peripheral collisions within uncertainties.

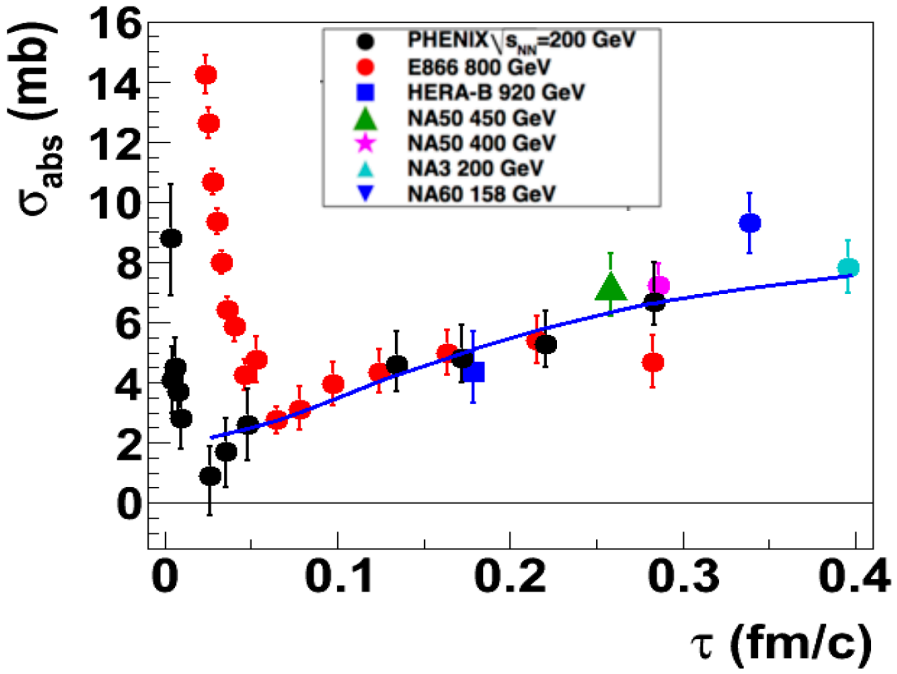
Calculations from Ferrerio et al. with two different PDFs shows a flat pT dependence (without Cronin). Strong disagree in central collisions.

PRC 87, 034904 (2013)

Systematic study of σ_{abs}

A very insightful shadowing corrected effective absorption cross-sections study:

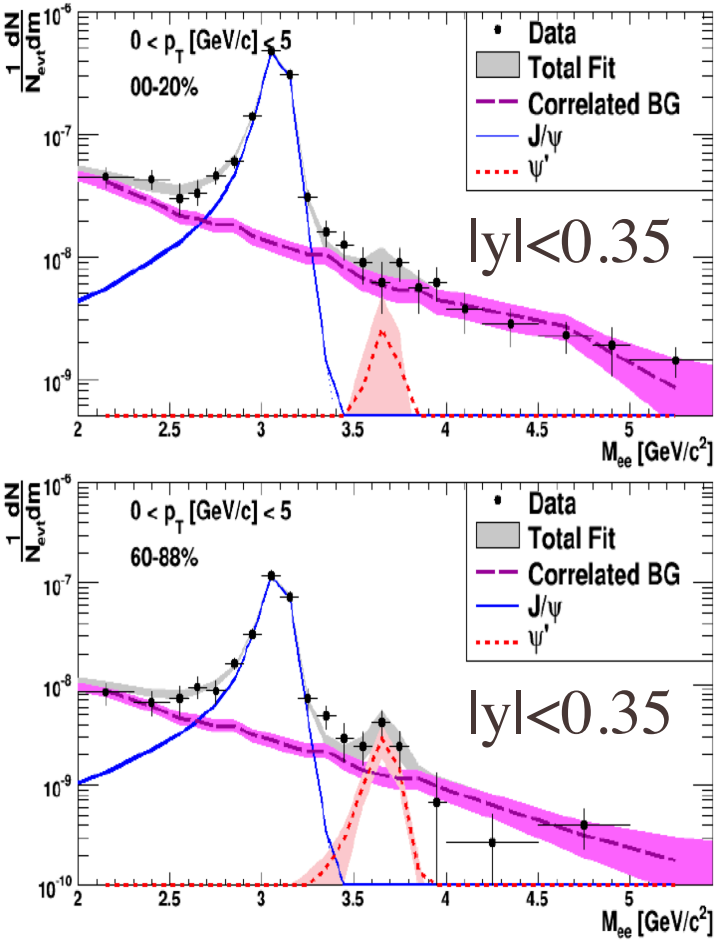
- After *cc* formation, the precursor pair expands as it crosses nucleus.
- Nuclear crossing time τ, vary strongly with rapidity.
- A break-up only makes sense if on time scale larger than the cc formation time.
- A nice trend above $\tau > 0.05$ fm.
- $\tau < 0.05$ fm, break-up does not make sense – too short time. Some other physics involved.



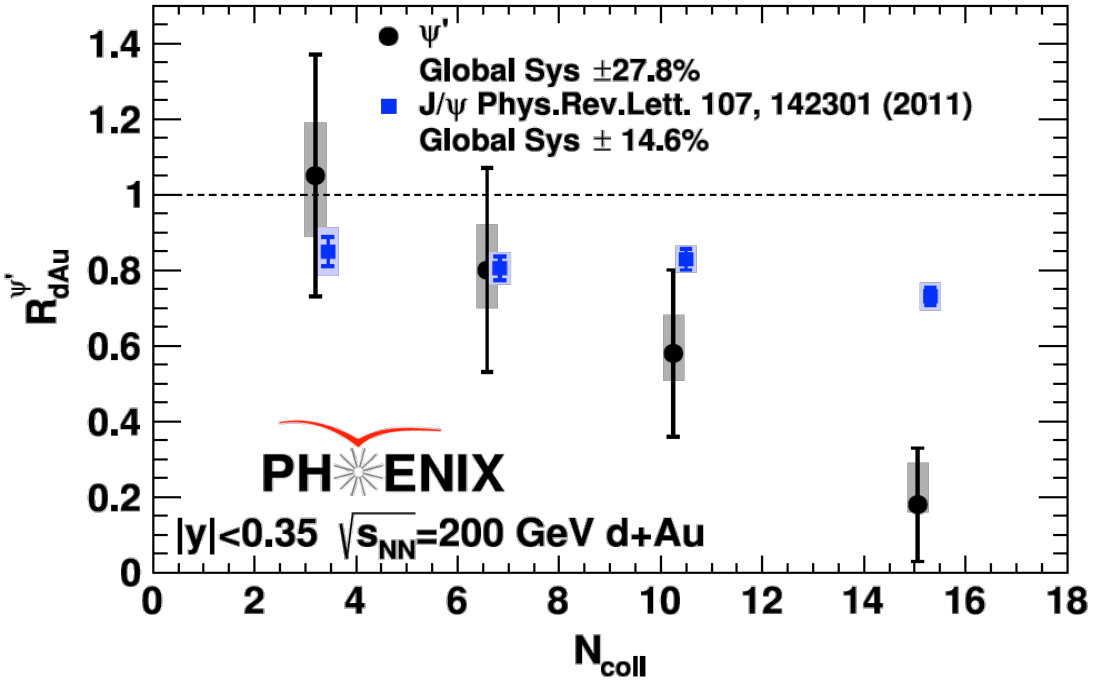
McGlinchey et al.
PRC87 (2013) 5, 054910

Caveat:
Shadowing and σ_{abs} are only considered.

ψ' R_{dAu}



PRL 111, 202301 (2013)

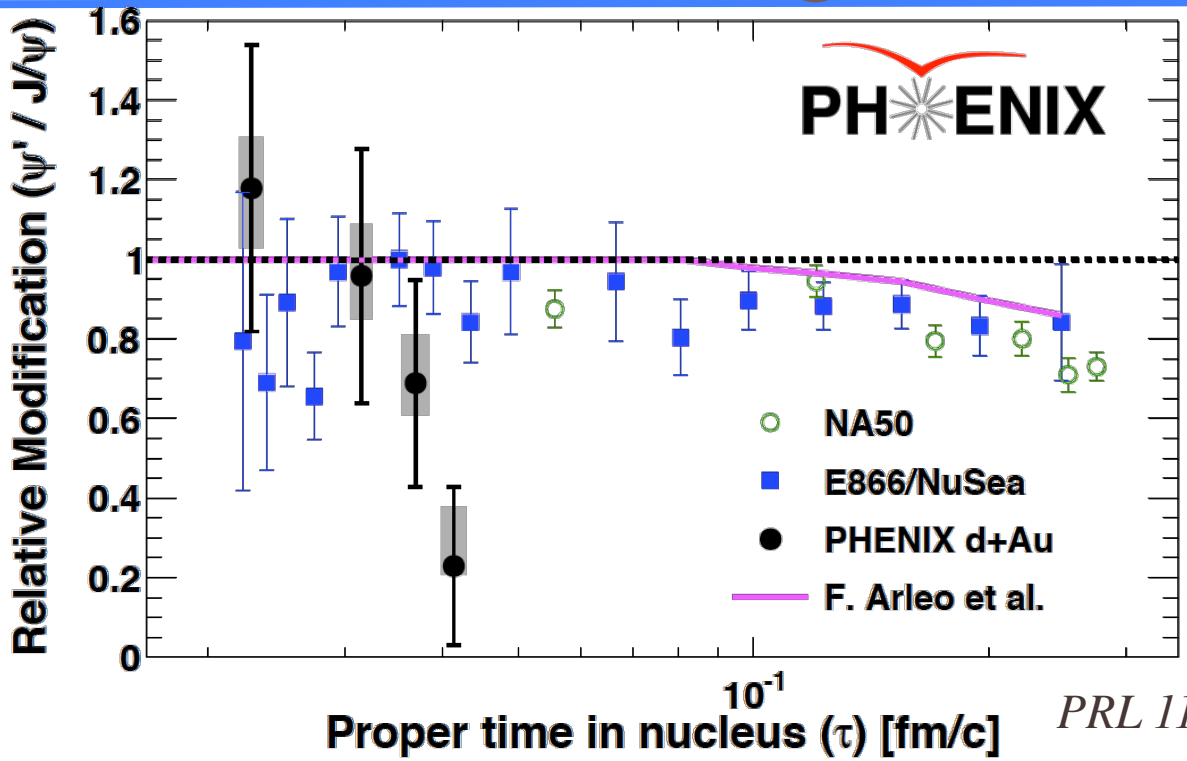


$$R_{dAu}{}^{\psi'} = \frac{[\psi'/(J/\psi)]^{dAu}}{[\psi'/(J/\psi)]^{pp}} R_{dAu}{}^{J/\psi},$$

Strong suppression of ψ' with increasing N_{coll} at the mid-rapidity.

Very unexpected results!!

Nuclear crossing time



PRL 111, 202301 (2013)

After ccbar formation, the pair expands as it crosses nucleus. Break-up makes sense **ONLY** on time scales larger than charm pair formation time.

Formation time ~ 0.15fm

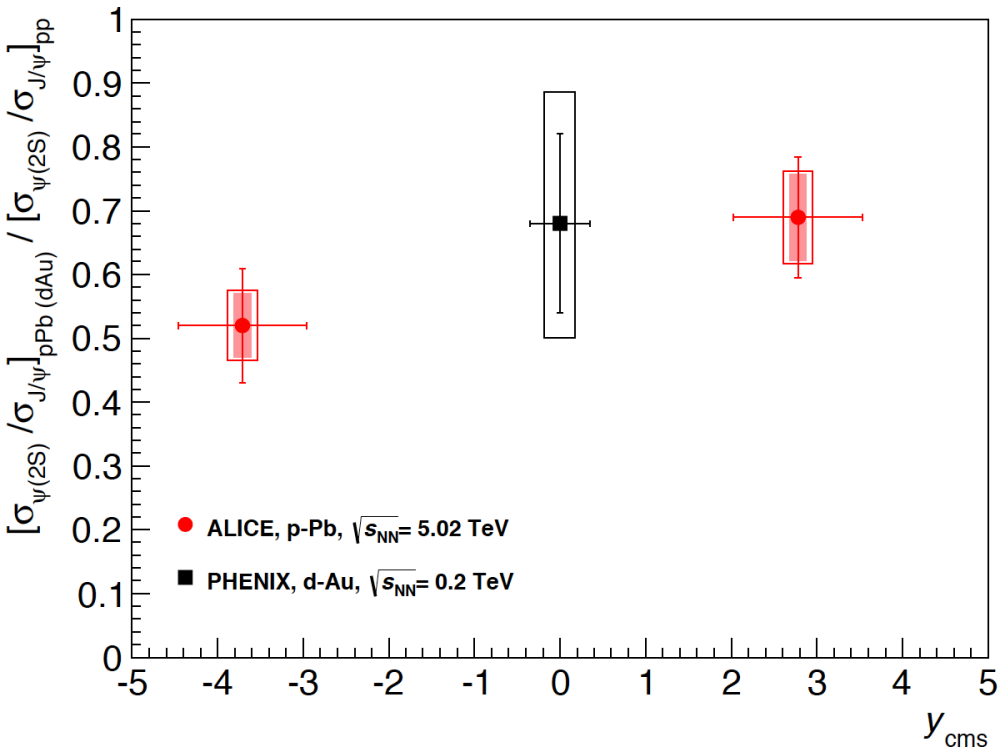
Nuclear crossing time ~0.05 fm at RHIC at midrapidity

Precursor crosses nucleus before final state forms! ψ' / J/ψ ratio should be ~1

Suppression outside the nucleus?

Small QGP? Or co-movers?

Confirmed by LHC



Similar affect seen at ALICE experiment.

Even a smaller nuclear crossing time at LHC.

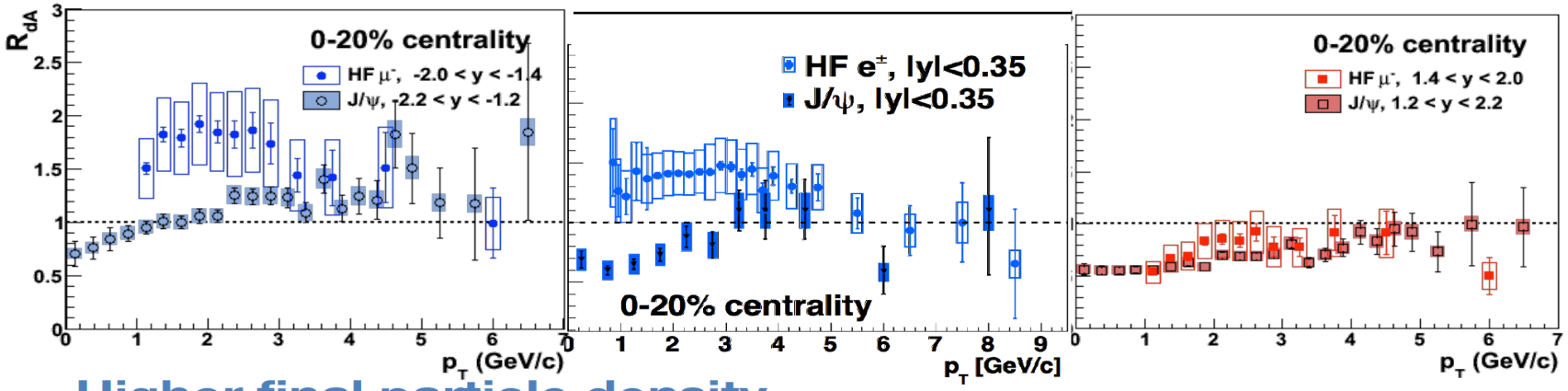
arXiv:1405.3796

Hot matter effects in p(d)+A

- Strong evidence of collective behavior in p(d)+A collisions both from RHIC and LHC.
- Looks like hydrodynamic expansion of a small hot-spot.
- Does it effect hard probes?

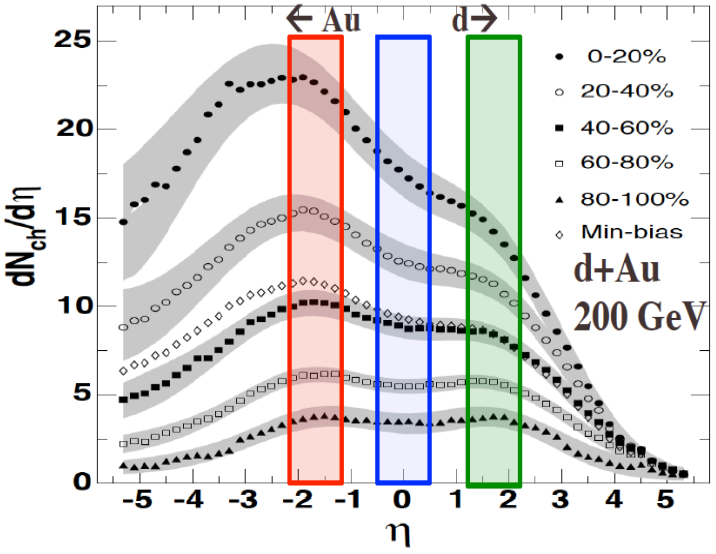
Sanity check: Open vs closed charm

arXiv:1310.1005, Phys.Rev.Lett. 109 (2012) 24, 242301, Phys.Rev. C87 (2013) 3, 034904



Higher final particle density

Probing lower-x gluons in Au

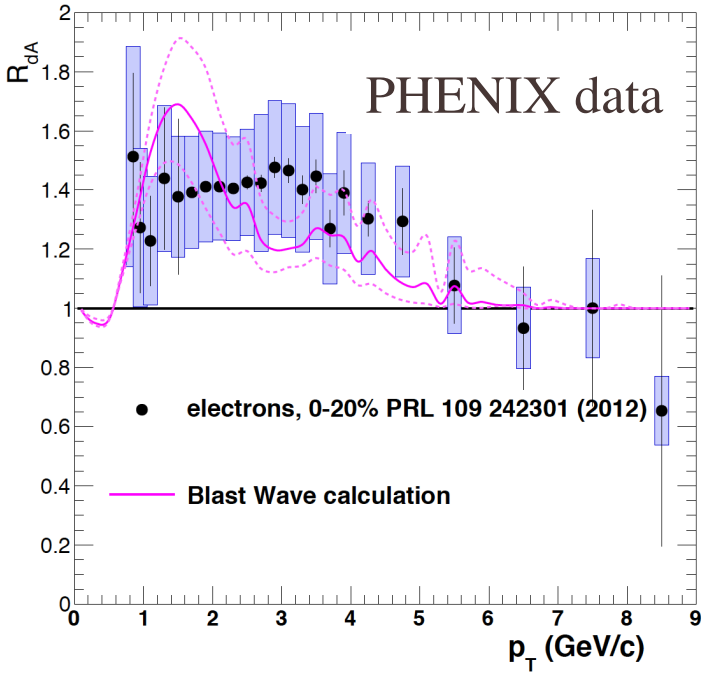


Caveat: Different kinematics

Same gluon-shadowing, energy loss and Cronin. A significant J/ψ break-up at backward rapidity.

..But.. HF enhancement at backward and mid rapidity are due to final state interaction?

Hydrodynamic behavior?



A. Sickles
Phys.Lett. B 731 (2014) 51-56

Possible radial flow?

Still a open question: p(d)+A collisions produce mini-QGP?

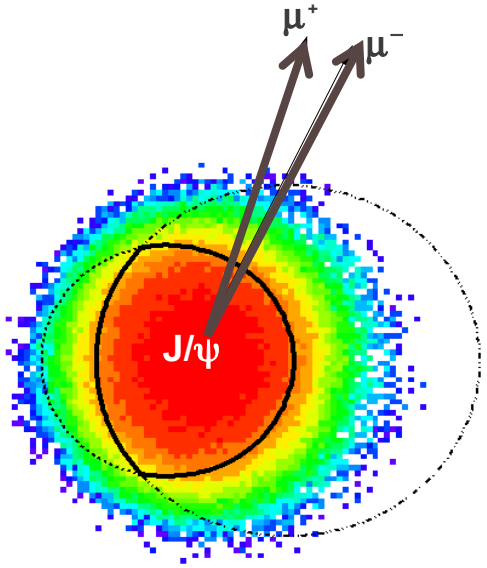
If its true, how does that feed back to our understanding of A+A collisions?

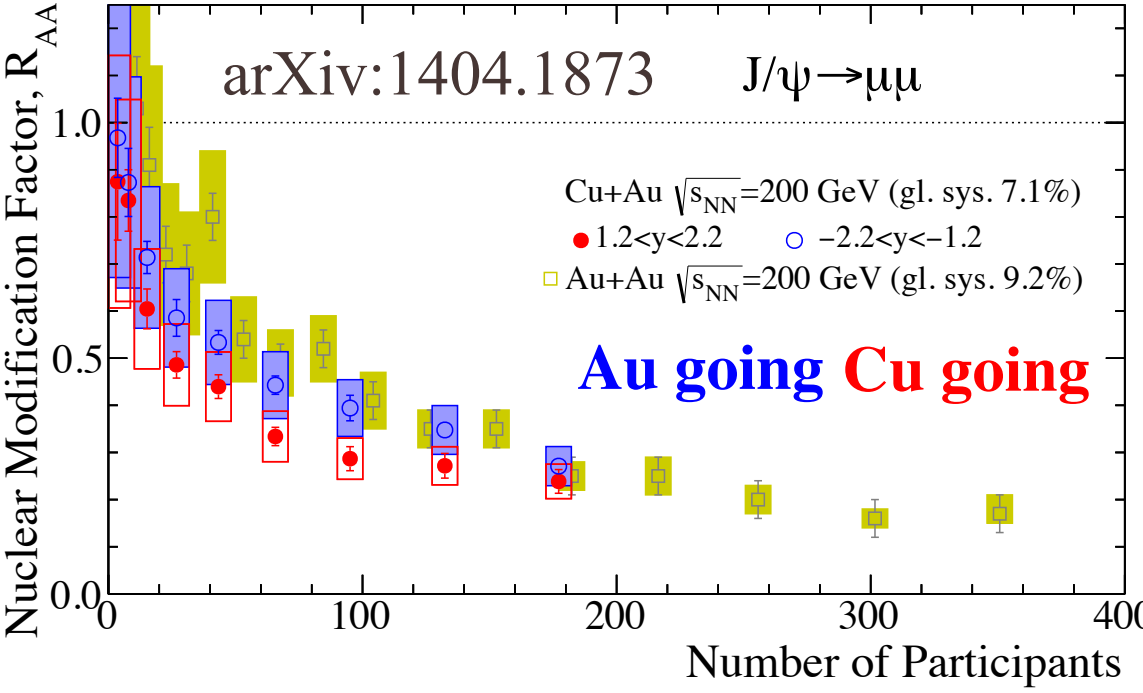
Lots of interesting results coming out of LHC and RHIC. Moving forward to a broader understanding.

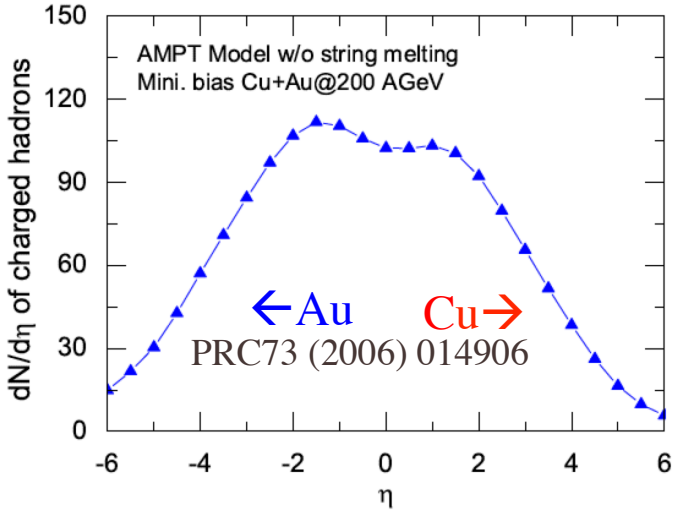
Cu+Au (new geometry)

Interplay between hot and cold nuclear matter effects

Cu+Au (new Geometry)





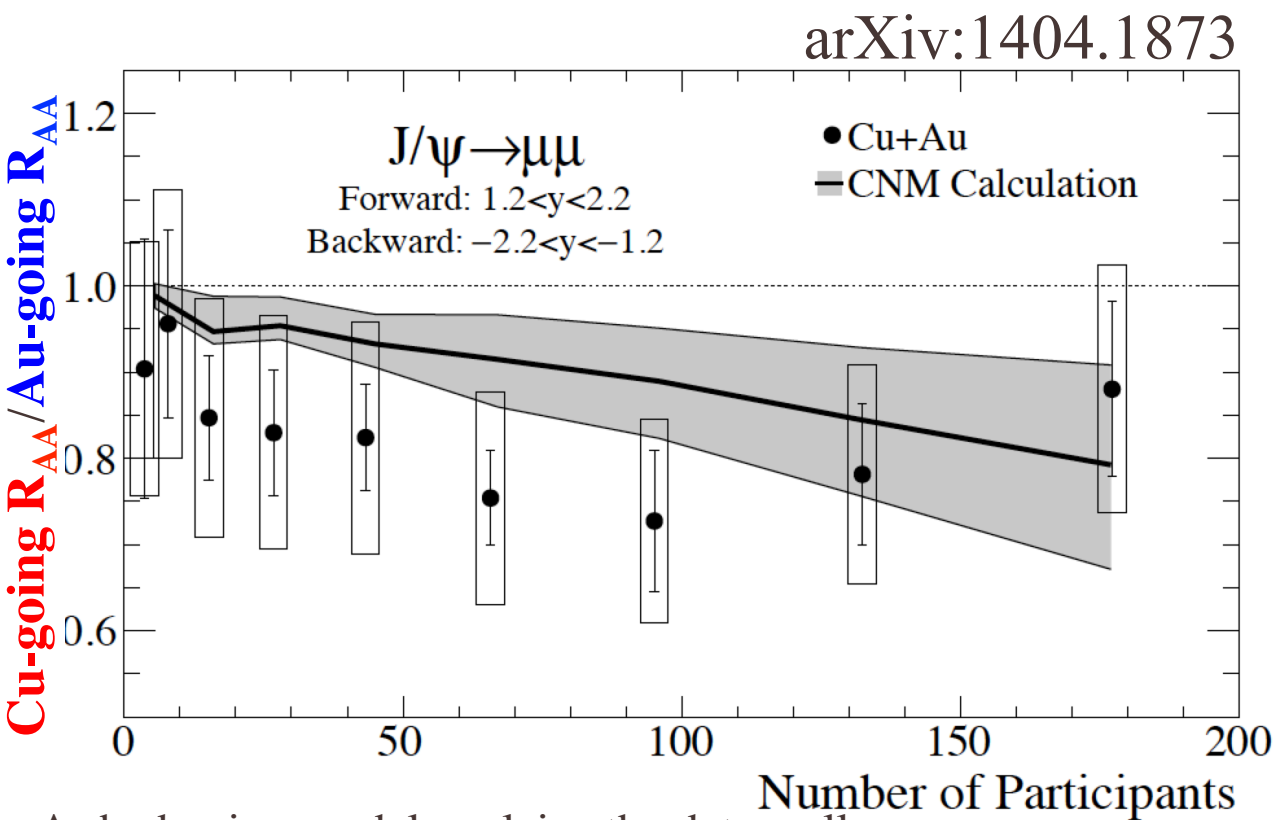


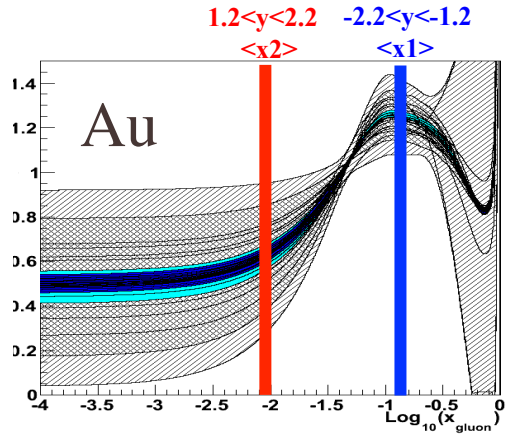
Asymmetric nuclear effects

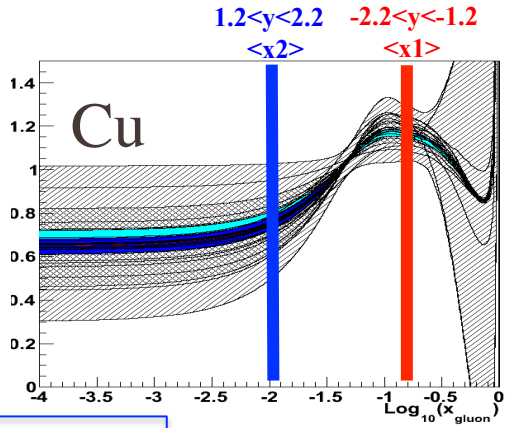
Higher suppression in region of lower particle density. Similar to d+Au collisions.

Hot nuclear matter effect would have effected the other way.

Cu-going-side/Au-going-side







A shadowing model explains the data well

Au-going direction :
low-x partons in Cu nucleus * high-x partons in Au nucleus

Cu-going direction:
low-x partons in Au nucleus * high-x partons in the Cu nucleus

Future of quarkonia at PHENIX

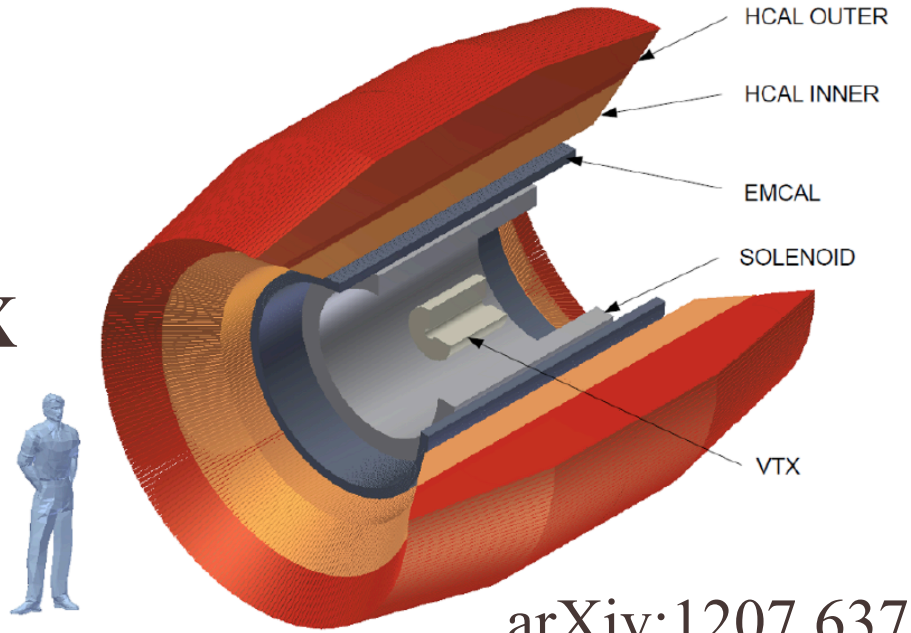
Today is special: Start of He3+Au run at RHIC

Coming soon in 2015

p+Si, p+Cu and p+Au at RHIC

Saga continues..

Long term plan: sPHENIX



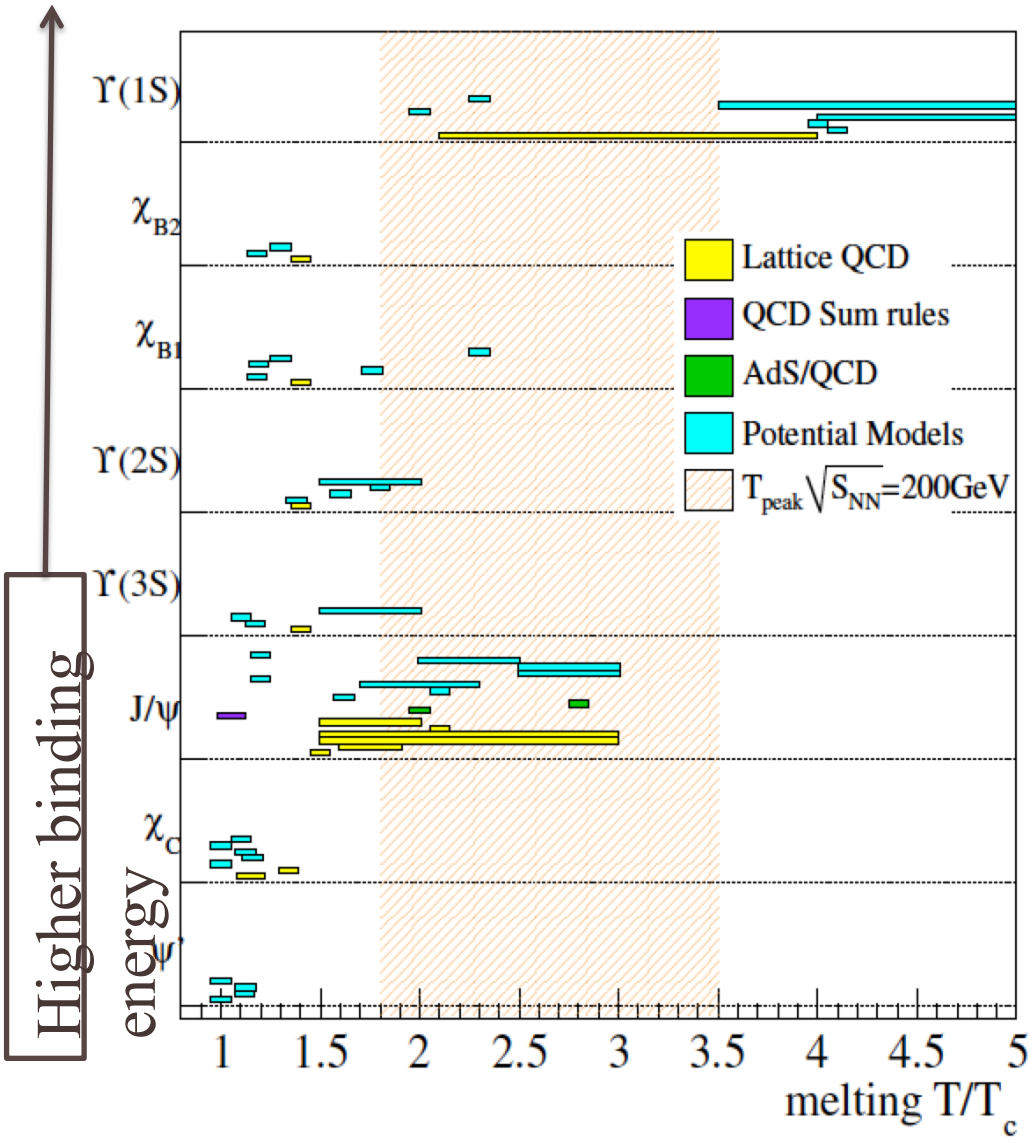
arXiv:1207.6378

Summary

- PHENIX measured quarkonia in a wide range of kinematic ranges in d+Au and Cu+Au collisions to understand CNM effects.
- CNM effects at forward and backward rapidity reflects different mechanisms, depending on nuclear crossing time.
- The magnitude and trend of ψ(2s) suppression in nuclear collisions is quite different from J/ψ. Nuclear crossing time does not explain the data.
- In Cu+Au collision, the Cu going side is more suppressed than Au going side due to CNM effects, sensitive to the low x of the Au nuclei.
- New dataset in near future: He3+Au, p+Si, p+Cu and p+Au will shed more light on CNM effects.

- BACK-UPS

Hot Medium effects



Matsui & Satz
PLB 178,

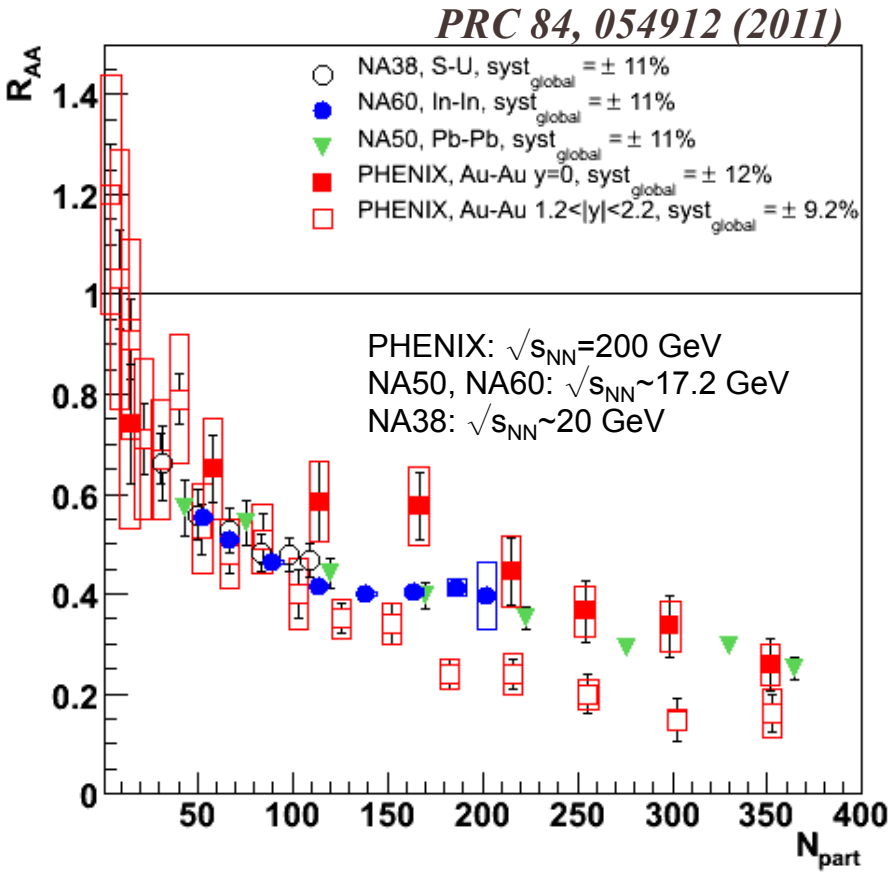
$$\lambda_D(T) = \sqrt{\frac{2}{9\pi\alpha_{\text{eff}}}}\frac{1}{T}$$

Different states have different binding energies.

Loosely bound states melt first!

Sequential suppression of individual states provides a "thermometer" of the QGP

J/ψ R_{AA} in A+A collisions



An overview of RAA measurements from 17-200GeV

A admixture of hot and cold nuclear effects which depends strongly on energy and rapidity.

NOT very instructive about the energy dependence pattern

Absorption energy dependence

• Usual parameterisation: (Glauber model)

$$S_{abs} = \exp(-\rho\, \sigma_{abs}\, L)$$

break-up cross section

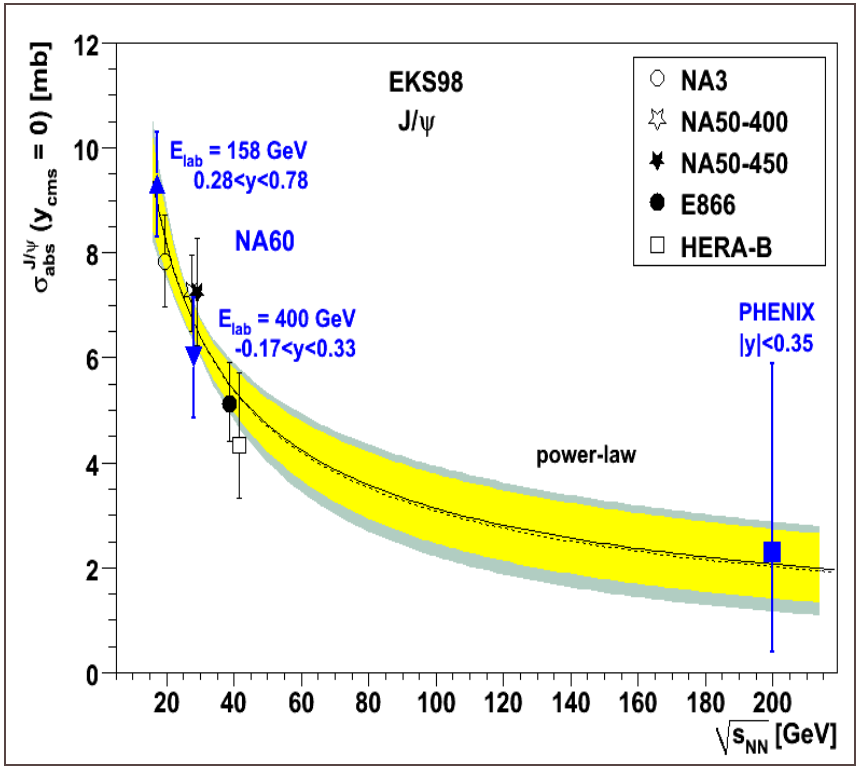
Energy dependence

• **At low energy**: the heavy system undergoes successive interactions with nucleons in its path and has to survive all of them => **Strong nuclear absorption**

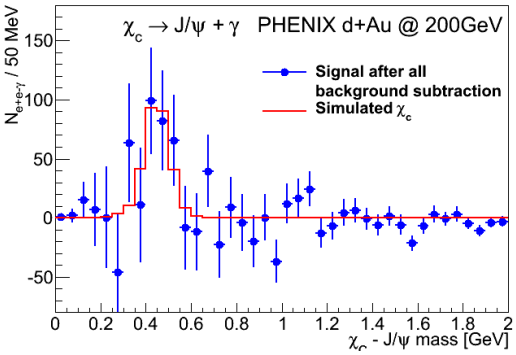
• **At high energy:** the coherence length is large and the projectile interacts with the nucleus as a whole => **Smaller nuclear absorption**

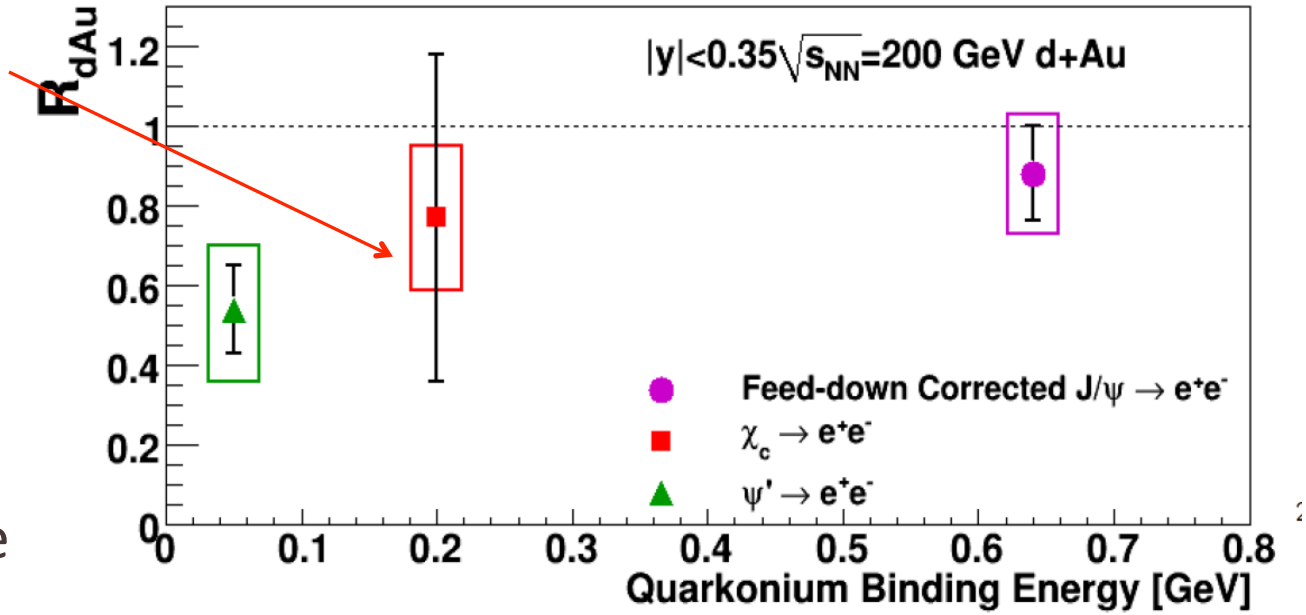
A systematic analysis at y~0 using EKS98 + σ_{abs} showed a clear **collision energy dependence** of σ_{abs}.

JHEP 0902:014 (2009)



χ_c in d+Au

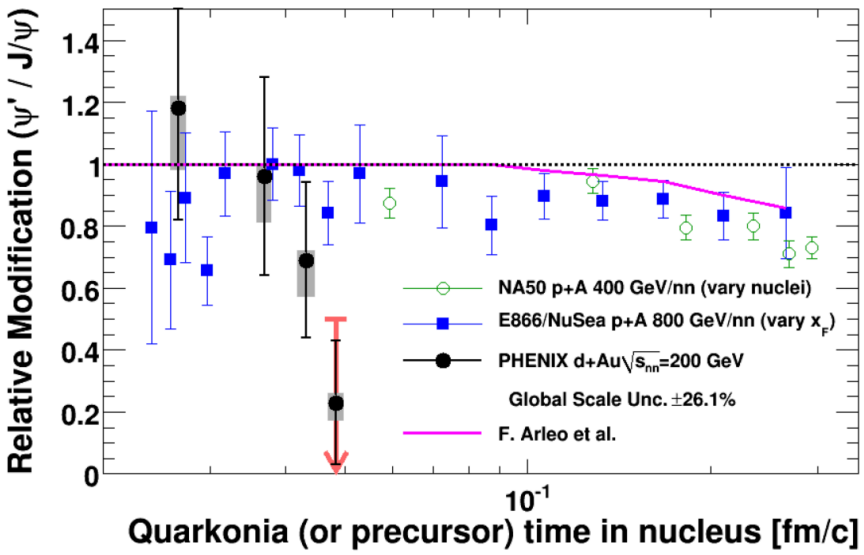


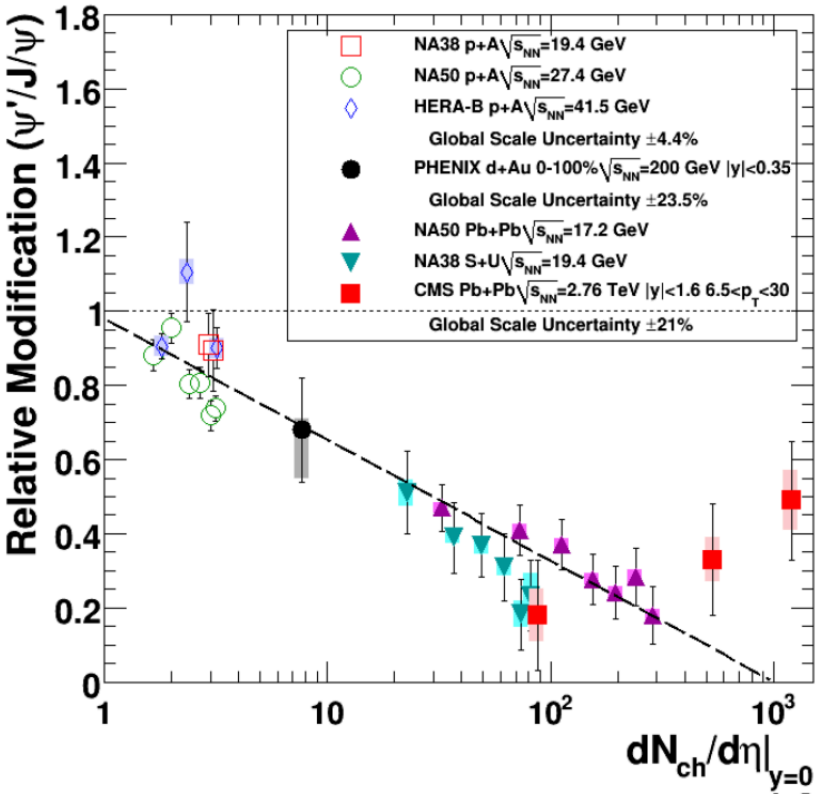


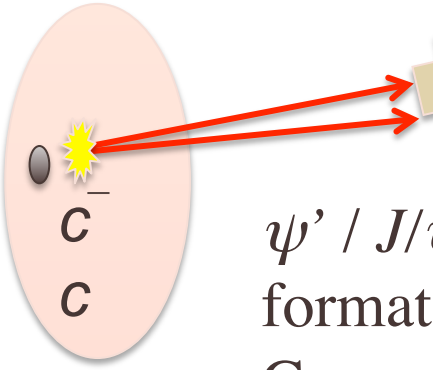
Charmonium R_{dAu} seems to depend on binding energy.

Better χ_c measureme is needed though.

Nuclear crossing time







ψ' / J/ψ ratio should be unity when the time in nucleus < formation time.

Curve is a model calculation based on NA50 and E866 data.

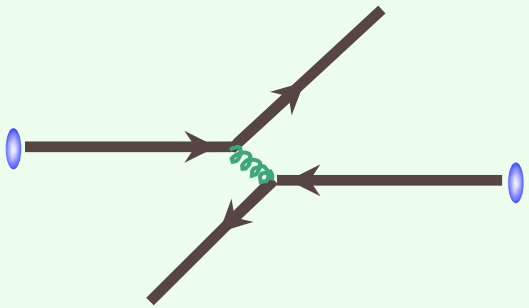
The relative modification scales well with charged particle mu

- **New PHENIX data is completely at odds with this**

Why p(d)+A collisions?

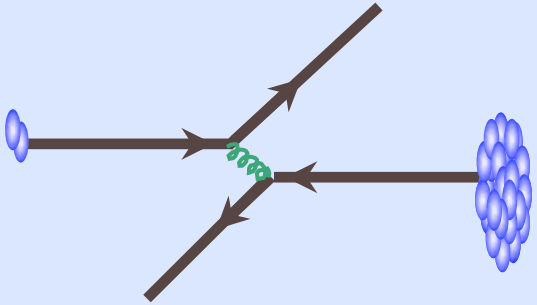
A very exciting time to talk about p(d)+A collisions

p+p measurements



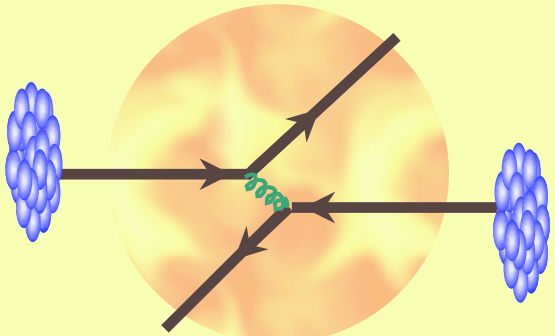
Baseline

d+A measurements



probe CNM effects

A+A measurements



probe HNM+CNM effects

QM 2012
Not enough particles to have collective behavior, control experiment

QM 2014
Are we sure?